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# Herculaneum Lead Study with a Risk Reduction Analysis

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## Abstract

*A survey of blood lead levels in children living within 2.4 kilometers of The Doe Run Company smelter in Herculaneum (Jefferson County), Missouri was conducted in August of 1984. The survey was modelled on a 1975 nationwide survey of heavy metal absorption in children living near primary non-ferrous smelters which included Herculaneum. The results of the 1984 survey were previously reported at the Environmental Trace Substances Conference held at the Columbia campus of the University of Missouri, USA in June 1986. An initial attempt was made in that paper to relate those blood leads to assumed environmental sources, including soil lead, that might explain the spatial pattern of blood leads observed. The results were satisfying enough to cause us to go back and measure soil lead concentrations and collect some household dust samples.*

*Based on these improvements in the field data (from Herculaneum and other authors) our understanding of soil ingestion by young children has been convincingly improved.*

*Armed with this calibrated model, we project additional drops in blood leads by 1990 due to anticipated food lead reductions. Using the 1984 baseline we made a sensitivity study of various soil, household dust, and air lead reductions projecting corresponding reductions in children's blood lead levels. It is clear from this and other work that additional reductions in air lead levels will have no significant impact on blood leads in Herculaneum. The sensitivity studies also show that the most impact can be gained by reducing household dust levels. However, the authors did not find health problems from lead in Herculaneum warranting such actions.*

## Introduction

The Doe Run Company (formerly St. Joe Lead Company at the site in question) operates a primary lead smelter in Herculaneum, Missouri,



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which is located on the Mississippi River 48 kilometers south of St. Louis, Missouri. The company began operations in 1892. The capacity of the plant has been about 199,700 metric tons of refined lead per year since the mid-1960's when the process was revamped. The smelter is bounded on the east by the river and the south by company owned land. The residential areas of

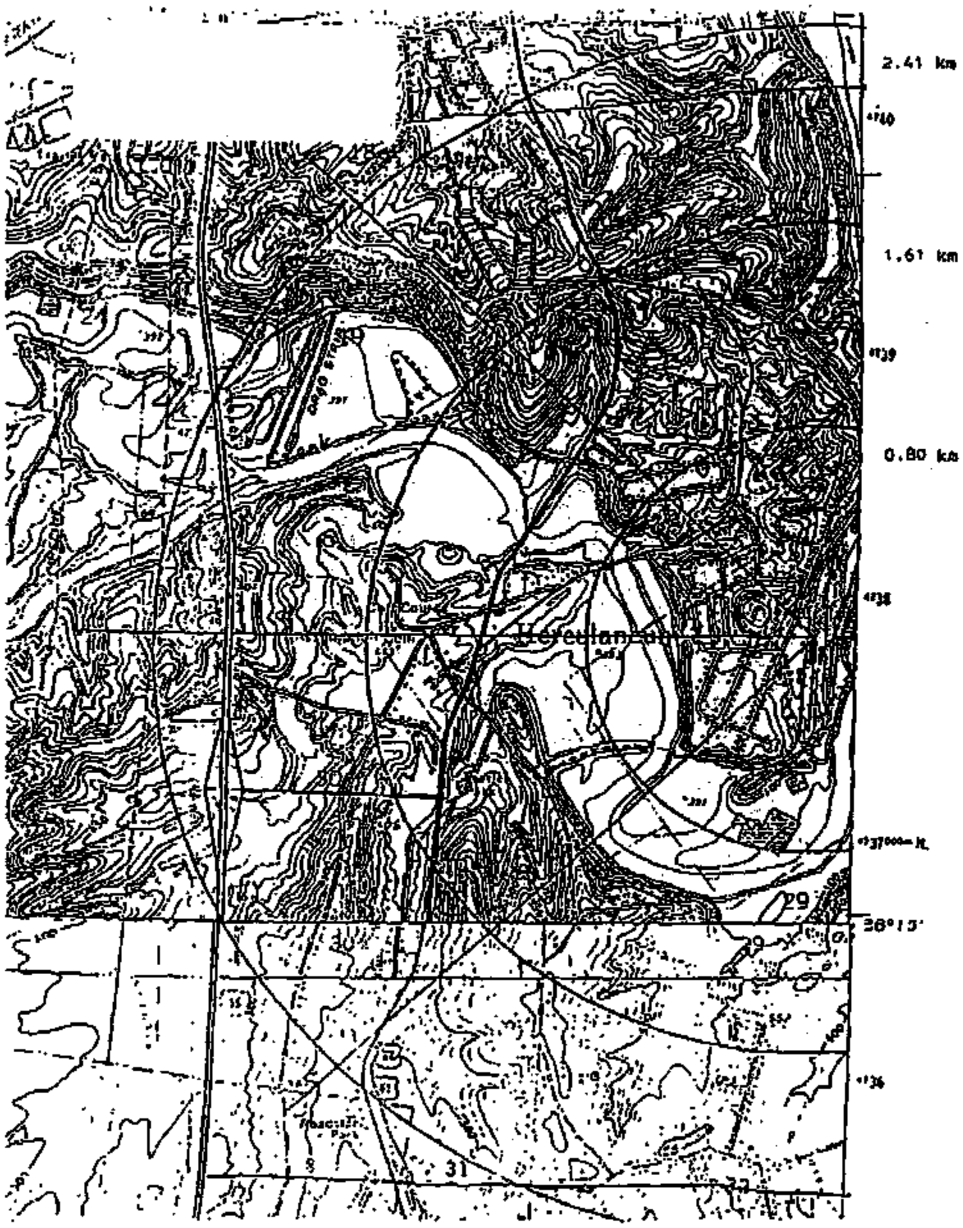


**Figure 1.** *Herculaneum, Missouri and environs.*

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Herculaneum are built up around the plant to the north and west of the smelter (see Figure 1). In 1975, as part of a nationwide survey, the blood lead levels of young children living around the smelter were determined.

Since that time the installation of pollution control equipment and the alteration of plant operating practices have reduced lead emissions. A new survey mimicking the 1975 methodology was conducted in 1984 by the Missouri Department of Health. The results of the 1984 survey were reported previously at the Environmental Trace Substances Conference in 1986 (Phillips, Vornberg). The costs of the study were borne equally between the company and the Health Department. Field work was accomplished in 1984 with the aid of the Jefferson County Health Department. In 1985 follow up work, was conducted to obtain soil samples and household dust samples from the households involved in the 1984 survey.

The environmental data were then loaded into the USEPA Biokinetic Uptake Model (USEPA, 1986) to compare the predicted blood leads with the measured blood leads. Sensitivity studies were conducted to determine which sources and pathways would offer the best hope of additional blood lead reductions should such reductions be justified.

## Methods

The methods of the 1975 blood lead survey and results were generally described by Baker *et al.* (1977). The 1984 survey and results were likewise reported previously (Phillips, 1986). Approximately 100 children were sampled in Herculaneum between the ages of 1-5 years of age in both studies.

The USEPA Biokinetic Uptake Model was installed using LOTUS software (Lotus Development Corporation, 1985) on a personal computer. The Herculaneum 1984 blood lead data were fitted to an adaptation of the EPA model (USEPA, 1986) arbitrarily designating geographic sectors around the plant. Site specific environmental data were also inserted into the model when appropriate.

Air lead data have been collected at a number of stations around the smelter for about 20 years using the standard EPA specification high volume sampler (USEPA, CFR 40 Part 50, "Reference Method for the Determination of Suspended Particulate in the Atmosphere"). When there was no high volume sampling station located in a sector an appropriate interpolation was made. The annual average air lead for that sector was then used in the model.

Soil lead data were collected from the obvious location where the child played in the yard, *e.g.* a swing set. If there was no obvious location, the centre of the backyard was selected. Soil samples of 7.6 cm in depth were taken using a section of a 5.1 cm diameter Shelby tube sampler. The samples were then extracted and placed in a marked plastic sample container for subsequent analysis for total lead.

A cleaning protocol of the sampling equipment was established between samples to insure against cross contamination. The possibility of affecting a result is remote at best due to the mass of the sample collected.

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Due to the presence of the smelter over a 100 year period, the amount of additional lead deposited between the 1984 blood lead sampling and the 1985 soil lead sampling is considered insignificant. Therefore, the 1985 soil lead results were used for 1984. Since the variability from site to site is large, only the average value is used for each sector as is the case for the blood leads.

Indoor house dust samples were collected from various homes in each sector from vacuum cleaners and analyzed for total lead as a percentage of total weight.

The only modifications to the USEPA Biokinetic Uptake Model are that the soil ingestion value has been changed to 60 $\mu$g/day (DeCesar, 1987) and the food uptakes have been modified for EPA predicted reductions (Sledge, 1986).

## Results

The results of blood lead and air lead data for 1975 and 1984 have been published previously (Baker, 1977; Phillips, 1986). The street/soil lead and indoor dust lead data are presented in Table 1 as the average by sector.

**Table 1.** *The street/soil lead and indoor dust lead data presented as the average by sector.*

| Sector | Range (km) | Street/soil Pb ($\mu$g/g) | Indoor dust Pb ($\mu$g/g) |
|---|---|---|---|
| N-NW | 0.00–0.80 | 1,458 | 2,080 |
| N-NW | 0.80–1.61 | 827 | 1,600 |
| N-NW | 1.61–2.41 | 148 | 630 |
| NW-W | 0.00–0.80 | 2,258 | 1,610 |
| NW-W | 0.80–1.61 | 508 | 975 |
| NW-W | 1.61–2.41 | – | – |
| W-SW | 0.00–0.80 | 2,239 | 1,210 |
| W-SW | 0.80–1.61 | 183 | 1,000 |
| W-SW | 1.61–2.41 | 70 | 850 |
| S-SW | 0.00–0.80 | 1,822 | 2,040 |
| S-SW | 0.80–1.61 | – | – |
| S-SW | 1.61–2.41 | 157 | 170 |

## Predictive Modelling

The predicted and measured blood leads are shown in Tables 2, 3, and 4 for 1975, 1984, and 1990 respectively. The correlations for 1975 and 1984 are very good. They have been shown again in Table 5 for easy comparison.

As Table 4 shows, for the 1990 projections, the average blood lead drops about 3.9 $\mu$g/dL from an observed 13.8 in 1984 to a predicted average of 9.9 $\mu$g/dL in 1990.

Another set of runs based on the 1990 baseline were made varying the street/soil, indoor dust, and air lead values as shown in Table 6. The corresponding predicted blood leads are also shown. Obviously, the most responsive drop is for household dust.

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Table 2. *Herculaneum blood lead study – 1975 data.*

| | Pevely N-NW | | N-NW | | N-NW | | NW-W | | NW-W | | W-SW | | W-SW | | S-WS | | Perryville | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sector-km from plant stack | 0 | 0.8 | 0.8 | 1.61 | 1.61 | 2.41 | 0 | 0.8 | 0.8 | 1.61 | 0 | 0.8 | 1.61 | 2.41 | 0 | 0.8 | | |
| 1. Outdoor air lead (µg/m³) | 4.5 | 4.5 | 2.6 | 2.6 | 1.2 | 1.2 | 4 | 4 | 1.6 | 1.6 | 1.2 | 1.2 | 0.6 | 0.6 | 1.6 | 1.6 | 0.5 | 0.5 |
| 2. Indoor air lead (µg/m³) | 1.35 | 1.35 | 0.78 | 0.78 | 0.36 | 0.36 | 1.20 | 1.20 | 0.48 | 0.48 | 0.36 | 0.36 | 0.18 | 0.18 | 0.48 | 0.48 | 0.15 | 0.15 |
| 3. Time spent outdoors (hours/day) | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 |
| 4. Time weighted average (µg/m³) | 1.61 | 1.98 | 0.93 | 1.08 | 0.43 | 0.50 | 1.43 | 1.67 | 0.57 | 0.67 | 0.43 | 0.50 | 0.21 | 0.25 | 0.57 | 0.67 | 0.18 | 0.21 |
| 5. Volume of air respired (m³/day) | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 |
| 6. Lead intake from air (µg/day) | 6.45 | 9.38 | 3.73 | 5.42 | 1.72 | 2.50 | 5.73 | 8.33 | 2.29 | 3.33 | 1.72 | 2.50 | 0.86 | 1.25 | 2.29 | 3.33 | 0.73 | 1.04 |
| 7. Deposition/absorption in lungs (%) | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 |
| 8. Total lead uptake from lungs (µg/day) | 2.9 | 7.0 | 1.7 | 4.1 | 0.8 | 1.9 | 2.6 | 6.3 | 1.0 | 2.5 | 0.8 | 1.9 | 0.4 | 0.9 | 1.0 | 2.5 | 0.3 | 0.8 |
| 9. Dietary lead consumption (µg/day) | | | | | | | | | | | | | | | | | | |
| a) natural lead, indirect atmospheric | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| b) from solder or other metals | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 |
| c) atmospheric lead | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 |
| d) undetermined sources | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| 10. Absorption in gut (%) | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 |
| 11. Dietary lead uptake (µg/day) | 21 | 26 | 21 | 26 | 21 | 26 | 21 | 26 | 21 | 26 | 21 | 26 | 21 | 26 | 21 | 26 | 21 | 26 |
| 12. Street dustfall lead (µg/g) | 1,458 | 1,438 | 827 | 827 | 148 | 148 | 2,258 | 2,258 | 988 | 988 | 2,239 | 2,239 | 683 | 683 | 1,822 | 1,822 | 140 | 138 |
| 13. Indoor dust lead (µg/g) | 2,080 | 2,080 | 1,400 | 1,400 | 630 | 630 | 1,610 | 1,610 | 975 | 975 | 1,210 | 1,210 | 1,400 | 1,000 | 2,040 | 2,040 | 380 | 380 |
| 14. Time weighted average (µg/g) | 1,976 | 1,873 | 1,471 | 1,342 | 590 | 469 | 1,718 | 1,826 | 897 | 819 | 1,302 | 1,353 | 864 | 728 | 2,004 | 1,967 | 668 | 557 |
| 15. Amount of dirt ingested (g/day) | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 16. Lead intake from dirt (µg/day) | 119 | 112 | 85 | 81 | 33 | 28 | 103 | 110 | 54 | 49 | 83 | 93 | 51 | 44 | 120 | 118 | 40 | 33 |
| 17. Dirt lead absorption in gut (%) | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 18. Lead uptake from dirt (µg/day) | 36 | 34 | 26 | 24 | 10 | 8 | 31 | 33 | 16 | 15 | 25 | 28 | 16 | 13 | 36 | 35 | 12 | 10 |
| 19. Total lead uptake from lung and gut (µg/day) | 59 | 67 | 49 | 54 | 31 | 36 | 54 | 65 | 38 | 43 | 46 | 56 | 38 | 40 | 58 | 64 | 33 | 37 |
| 20. Predicted blood lead | 24 | 27 | 19 | 22 | 12 | 14 | 22 | 26 | 15 | 17 | 18 | 22 | 15 | 16 | 23 | 26 | 13 | 15 |
| 21. Observed blood lead | 30 | 30 | 19.3 | 19.3 | 16.9 | 16.9 | 24.3 | 24.3 | 32.3 | 32.3 | 17.3 | 17.3 | 11.1 | 11.1 | 21.3 | 21.3 | 16.9 | 16.9 |
| 22. Ratio predicted/observed blood lead | 0.8 | 0.9 | 1.0 | 1.1 | 0.7 | 0.9 | 0.9 | 1.1 | 0.5 | 0.5 | 1.1 | 1.3 | 1.3 | 1.4 | 1.1 | 1.2 | 0.8 | 0.9 |
| 23. Number of children tested | 8 | | 13 | | 22 | | 3 | | 1 | | 5 | | 1 | | 3 | | 85 | |

Table 3. *Herculaneum blood lead study – 1984 data.*

| | N-NW | | N-NW | | N-NW | | Fovely NW- | | NW-W | | W-SW | | W-SW | | W-SW | | SW-S | | SW-S | | Fetus | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sector-km from plant stack | 0 | 0.8 | 0.8 | 1.61 | 1.61 | 2.41 | 0 | 0.8 | 0.8 | 1.61 | 0 | 0.8 | 0.8 | 1.61 | 1.61 | 2.41 | 0 | 0.8 | 1.61 | 2.41 | | |
| 1. Outdoor air lead (μg/m³) | 2.8 | 2.8 | 1.1 | 1.1 | 0.8 | 0.8 | 3.2 | 3.2 | 0.8 | 0.8 | 0.8 | 0.8 | 0.5 | 0.5 | 0.3 | 0.3 | 0.8 | 0.8 | 0.03 | 0.03 | 0.02 | 0.02 |
| 2. Indoor air lead (μg/m³) | 0.84 | 0.84 | 0.33 | 0.33 | 0.24 | 0.24 | 0.66 | 0.66 | 0.24 | 0.24 | 0.24 | 0.24 | 0.15 | 0.15 | 0.09 | 0.09 | 0.34 | 0.34 | 0.09 | 0.09 | 0.06 | 0.06 |
| 3. Time spent outdoors (hours/day) | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 1 | 4 |
| 4. Time weighted average (μg/m³) | 1.00 | 1.17 | 0.39 | 0.46 | 0.29 | 0.33 | 0.79 | 0.92 | 0.29 | 0.33 | 0.29 | 0.33 | 0.18 | 0.21 | 0.11 | 0.13 | 0.29 | 0.33 | 0.11 | 0.13 | 0.07 | 0.08 |
| 5. Volume of air respired (m³/day) | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 |
| 6. Lead intake from air (μg/day) | 4.01 | 5.83 | 1.58 | 2.29 | 1.15 | 1.67 | 3.15 | 4.58 | 1.15 | 1.67 | 1.15 | 1.67 | 0.72 | 1.04 | 0.43 | 0.63 | 1.15 | 1.67 | 0.43 | 0.63 | 0.29 | 0.42 |
| 7. Deposition/absorption in lungs (%) | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 |
| 8. Total lead uptake from lungs (μg/day) | 1.8 | 4.4 | 0.7 | 1.7 | 0.5 | 1.3 | 1.4 | 3.4 | 0.5 | 1.3 | 0.5 | 1.3 | 0.3 | 0.8 | 0.1 | 0.5 | 0.5 | 1.3 | 0.2 | 0.5 | 0.1 | 0.3 |
| 9. Dietary lead consumption (μg/day) | | | | | | | | | | | | | | | | | | | | | | |
| *a) natural lead/indirect atmospheric* | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| b) from solder or other metals | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 |
| c) atmospheric lead | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| d) undetermined sources | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| 10. Absorption in gut (%) | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 |
| 11. Dietary lead uptake (μg/day) | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 | 8 | 10 |
| 12. Street dust/soil lead (μg/g) | 1,458 | 1,458 | 827 | 827 | 148 | 148 | 3,258 | 3,258 | 508 | 508 | 2,239 | 2,239 | 183 | 183 | 78 | 78 | 1,832 | 1,822 | 157 | 157 | 110 | 110 |
| 13. Indoor dust lead (μg/g) | 2,080 | 2,080 | 1,600 | 1,600 | 630 | 630 | 1,610 | 1,610 | 975 | 975 | 1,210 | 1,210 | 1,000 | 1,000 | 850 | 850 | 2,040 | 2,040 | 170 | 170 | 780 | 780 |
| 14. Time weighted average (μg/g) | 1,976 | 1,873 | 1,471 | 1,342 | 550 | 469 | 1,718 | 1,826 | 897 | 819 | 1,382 | 1,553 | 864 | 728 | 720 | 598 | 2,004 | 1,967 | 168 | 166 | 668 | 537 |
| 15. Amount of dirt ingested (g/day) | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 16. Lead intake from dirt (μg/day) | 119 | 112 | 88 | 81 | 33 | 28 | 103 | 110 | 54 | 49 | 83 | 93 | 52 | 44 | 43 | 39 | 120 | 118 | 10 | 10 | 40 | 33 |
| 17. Dirt lead absorption in gut (%) | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 18. Lead uptake from dirt (μg/day) | 36 | 34 | 26 | 24 | 10 | 8 | 31 | 33 | 16 | 15 | 25 | 28 | 16 | 13 | 13 | 11 | 36 | 35 | 3 | 3 | 12 | 10 |
| 19. Total lead uptake from lung and gut (μg/day) | 45 | 48 | 35 | 36 | 18 | 20 | 40 | 46 | 25 | 26 | 33 | 39 | 24 | 24 | 21 | 21 | 45 | 47 | 11 | 14 | 20 | 20 |
| 20. Predicted blood lead | 18 | 19 | 14 | 14 | 7 | 8 | 16 | 19 | 10 | 10 | 13 | 16 | 10 | 10 | 8 | 8 | 18 | 19 | 4 | 5 | 8 | 8 |
| 21. Observed blood lead | 19.2 | 19.2 | 12.6 | 12.6 | 9.9 | 9.9 | 17.4 | 17.4 | 11.3 | 11.3 | 22.3 | 22.3 | 10.4 | 10.4 | 7.4 | 7.4 | 16.8 | 16.8 | 8.4 | 8.4 | 8 | 8 |
| 22. Ratio predicted/observed blood lead | 0.9 | 1.0 | 1.1 | 1.1 | 0.7 | 0.8 | 0.9 | 1.1 | 0.9 | 0.9 | 0.6 | 0.7 | 0.9 | 0.9 | 1.1 | 1.1 | 1.1 | 1.1 | 0.5 | 0.6 | 1.0 | 1.0 |
| 23. Number of children tested | 13 | | 15 | | 33 | | 22 | | 10 | | 12 | | 5 | | 5 | | 5 | | 9 | | 100 | |
| 24. Average predicted blood lead | 12.4 | | | | | | | | | | | | | | | | | | | | | |

**Table 4.** *Herculaneum blood lead study – 1990 data.*

| Sector-km from plant stack | N-NW 0 | N-NW 0.8 | N-NW 0.8 | N-NW 1.61 | N-NW 1.61 | N-NW 3.41 | NW-W 0 | NW-W 0.8 | NW-W 0.8 | NW-W 1.61 | W-SW 0 | W-SW 0.8 | W-SW 0.8 | W-SW 1.61 | W-SW 1.61 | W-SW 3.41 | SW-S 0 | SW-S 0.8 | SW-S 1.61 | SW-S 3.41 | Fetus | Fetus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Outdoor air lead (µg/m³) | 1.5 | 1.5 | 0.5 | 0.5 | 0.2 | 0.2 | 1.4 | 1.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.3 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 |
| 2. Indoor air lead (µg/m³) | 0.45 | 0.45 | 0.15 | 0.15 | 0.06 | 0.06 | 0.42 | 0.42 | 0.12 | 0.12 | 0.15 | 0.15 | 0.09 | 0.09 | 0.06 | 0.06 | 0.12 | 0.12 | 0.06 | 0.06 | 0.06 | 0.06 |
| 3. Time spent outdoors (hours/day) | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 |
| 4. Time weighted average (µg/m³) | 0.54 | 0.63 | 0.18 | 0.21 | 0.07 | 0.08 | 0.50 | 0.58 | 0.14 | 0.17 | 0.18 | 0.21 | 0.11 | 0.13 | 0.07 | 0.08 | 0.14 | 0.17 | 0.07 | 0.08 | 0.07 | 0.08 |
| 5. Volume of air respired (m³/day) | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 4 | 5 |
| 6. Lead intake from air (µg/day) | 2.15 | 3.13 | 0.72 | 1.04 | 0.29 | 0.42 | 2.01 | 2.92 | 0.57 | 0.83 | 0.72 | 1.04 | 0.43 | 0.63 | 0.29 | 0.42 | 0.57 | 0.83 | 0.29 | 0.42 | 0.29 | 0.42 |
| 7. Deposition/absorption in lungs (%) | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 | 45 | 75 |
| 8. Total lead uptake from lungs (µg/day) | 1.0 | 3.3 | 0.3 | 0.8 | 0.1 | 0.3 | 0.9 | 2.2 | 0.3 | 0.6 | 0.3 | 0.8 | 0.2 | 0.5 | 0.1 | 0.3 | 0.3 | 0.6 | 0.1 | 0.3 | 0.1 | 0.3 |
| 9. Dietary lead consumption (µg/day) | | | | | | | | | | | | | | | | | | | | | | |
| a) natural lead, indirect atmosphere | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| b) from solder or other metals | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| c) atmospheric lead | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| d) undetermined sources | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| 10. Absorption in gut (%) | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 | 42 | 53 |
| 11. Dietary lead uptake (µg/day) | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 4 |
| 12. Street dust/soil lead (µg/g) | 1,458 | 1,458 | 827 | 827 | 148 | 148 | 2,258 | 2,258 | 500 | 500 | 2,239 | 2,239 | 183 | 183 | 70 | 70 | 1,822 | 1,822 | 157 | 157 | 110 | 110 |
| 13. Indoor dust lead (µg/g) | 2,080 | 2,080 | 1,600 | 1,600 | 430 | 430 | 1,610 | 1,610 | 975 | 975 | 1,200 | 1,200 | 1,080 | 1,080 | 850 | 850 | 2,040 | 2,040 | 170 | 170 | 780 | 780 |
| 14. Time weighted average (µg/g) | 1,976 | 1,873 | 1,471 | 1,343 | 550 | 469 | 1,718 | 1,826 | 897 | 819 | 1,302 | 1,533 | 664 | 728 | 729 | 590 | 2,004 | 1,967 | 168 | 166 | 606 | 537 |
| 15. Amount of dirt ingested (g/day) | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| 16. Lead intake from dirt (µg/day) | 119 | 112 | 88 | 81 | 33 | 28 | 103 | 110 | 54 | 49 | 83 | 93 | 52 | 44 | 43 | 35 | 120 | 118 | 10 | 10 | 40 | 33 |
| 17. Dirt lead absorption in gut (%) | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 18. Lead uptake from dirt (µg/day) | 36 | 34 | 26 | 24 | 10 | 8 | 31 | 33 | 16 | 15 | 25 | 28 | 16 | 13 | 13 | 11 | 36 | 35 | 3 | 3 | 12 | 10 |
| 19. Total lead uptake from lung and gut (µg/day) | 40 | 40 | 30 | 29 | 13 | 13 | 35 | 39 | 19 | 19 | 28 | 33 | 19 | 17 | 16 | 15 | 39 | 40 | 6 | 7 | 15 | 14 |
| 20. Predicted blood lead | 16 | 16 | 12 | 12 | 5 | 5 | 14 | 16 | 8 | 8 | 11 | 13 | 8 | 7 | 6 | 6 | 16 | 16 | 2 | 3 | 6 | 6 |
| 21. Predicted average blood lead | 9.9 | | | | | | | | | | | | | | | | | | | | | |

**Table 5.** *The street/soil, indoor dust, and air lead values. The corresponding predicted blood leads are also shown.*

| Sector | Range (km) | 1975 Pred. ($\mu$g/dL) | 1975 Actual ($\mu$g/dL) | 1984 Pred. ($\mu$g/dL) | 1984 Actual ($\mu$g/dL) |
|---|---|---|---|---|---|
| N-NW | 0.00–0.80 | 25.5 | 30.0 | 18.5 | 19.2 |
| N-NW | 0.80–1.61 | 20.5 | 19.3 | 14.0 | 12.6 |
| N-NW | 1.61–2.41 | 13.0 | 16.9 | 7.5 | 9.9 |
| NW-W | 0.00–0.80 | 24.0 | 24.3 | 17.5 | 17.4 |
| NW-W | 0.80–1.61 | 16.0 | 32.3 | 10.0 | 11.3 |
| NW-W | 1.61–2.41 | – | – | – | – |
| W-SW | 0.00–0.80 | 20.0 | 17.3 | 14.5 | 22.3 |
| W-SW | 0.80–1.61 | – | – | 10.0 | 10.4 |
| W-SW | 1.61–2.41 | 15.5 | 11.1 | 8.0 | 7.4 |
| S-SW | 0.00–0.80 | 25.0 | 21.3 | 18.5 | 16.8 |
| S-SW | 0.80–1.61 | – | – | – | – |
| S-SW | 1.61–2.41 | – | – | 4.5 | 8.4 |

Pred.=predicted.

**Table 6.** *1990 modelling sensitivity analysis.*

| Scenario | Predicted average | % reduction from baseline |
|---|---|---|
| 1990 baseline blood lead average | 9.9 | |
| 50% reduction in estimated 1990 air leads | 9.8 | 1.0 |
| 100% reduction in estimated 1990 air leads | 9.7 | 2.0 |
| 85% reduction in street dust/soil lead | 8.6 | 13.1 |
| 50% reduction in indoor dust lead | 6.6 | 33.3 |
| 75% reduction in indoor dust lead | 5.0 | 49.5 |

## Conclusion and Recommendation

As a result of the study at Herculaneum, the authors are advocating that the biokinetic uptake model or a subsequent more sophisticated version, be used in developing a strategy to reduce blood leads in a community where a documented health problem exists. It is clear from the predictive power of this tool that we have moved beyond designating a simple soil lead standard or air lead standard and we must attack the problem on a case by case basis analyzing all of the sources and pathways. In addition, we must not overlook house-specific plumbing, paint, or ceramicware problems.

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Sledge, Donna. 1986. Ms Donna Sledge is employed by the USEPA Office of Air Quality Planning and Standards. Personal communication from Ms Sledge to Mr Vornberg on August 19, 1986 informed him during a telephone conversation of the expected lead reductions the USEPA has for dietary lead uptake due to projected lead reductions in the American diet. These expected lead reductions due to decreased lead in diet are reflected in Table 4, the 1990 projected blood leads.

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